Fault Evaluation Report FER-164

Faults in the southern Hollister area, San Benito County

by

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INTRODUCTION

Potentially active faults located in San Benito County south of Hollister that are evaluated in this FER include the San Andreas, Calaveras, Paicines, Tres Pinos, Quien Sabe, and related faults (figure 1). Most of these faults were zoned for special studies in 1974 in the Tres Pinos, Paicines, and Cherry Peak 7.5-minute quadrangles (CDMG, 1974a-1974c). Some faults in these quadrangles may not be Holocene active and most of the zones appear to be unnecessarily wide. In addition, faults that may be active (Holocene) were not zoned in 1974 (e.g., in the Three Sisters quadrangle). These faults are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act (Hart, 1980).

SUMMARY OF AVAILABLE DATA

The southern Hollister study area is characterized by compressional ? r-l strike slip ? tectonics of the San Andreas fault system. Topography in the study area ranges from the relatively flat to gently sloping surfaces of the Hollister Valley to the relatively rugged hills of the Gabilan Range along the southwestern part of the study area and the Diablo Range on the northeastern part of the study area. Elevations in the study area range from about 200 feet to about 3,000 feet. Development in the area is sparse and is generally limited to the outlying areas of Hollister. However, agricultural use is very extensive and most flat-lying areas have been cultivated for perhaps greater than 100 years. Gently rolling hills typically are used for grazing land.

Predominant rock types in the study area include Mesozoic crystalline basement rocks west of the San Andreas fault, Mesozoic marine sedimentary rocks, Tertiary marine, non-marine and volcanic rocks, and Quaternary surficial deposits (Wilson, 1943; Taliaferro, 1945; Kilburn, 1972; Dibblee and Rogers, 1975; Dibblee, 1979a, b, c). Quaternary surficial deposits include the landslide-prone Plio-Pleistocene San Benito Gravels, Pleistocene lacustrine deposits (Jenkins, 1973), late Pleistocene and Holocene alluvium and terrrace deposits, and Holocene colluvium (Dibblee, 1979a, b, c; Dibblee and Rogers, 1975; Kilburn, 1972; U.S.S.C.S., 1969). Terrace deposits of the San Benito River and Tres Pinos Creek lie along the trends of the San Andreas, Calaveras, Paicines, and Tres Pinos faults and provide a reasonably good, though complex, relationship between late Pleistocene and Holocene sedimentation and fault displacement (Harms, et al., 1984; J. Perkins and J. Sims, p.c., October 1984).

SAN ANDREAS FAULT

The San Andreas fault is a major right-lateral strike-slip fault which generally delineates the transform plate boundary between the Pacific and North American plates. Quaternary-active traces of the San Andreas fault in the Paicines and Cherry Peak 7-1/2-minute quadrangles were zoned for special studies in 1974 (figures 2c, 2d). Fault traces zoned for special studies were based on mapping by Brown (1970) in the Paicines quadrangle and Wilson (1943) and Brown (1970) in the Cherry Peak quadrangle (figures 2c, 2d). In addition, aerial photographic lineaments mapped by CDMG staff were also included in the special studies zones (SSZ) maps (locality 1, figure 2c). These photo lineaments were not field checked.

Brown (1970) mapped recenty active traces of the San Andreas fault at a scale of 1:62,500. Fault traces are annotated with geomorphic and other evidence of recent activity (figures 2c, 2d). Brown stated that the accuracy of fault locations ranges from within 100 feet to 200 feet or greater in areas with sparse topographic control. Wilson (1943) noted that the San Andreas fault in the Cherry Peak quadrangle was characterized by topographic evidence of recent movement, such as sag ponds, narrow troughs, scarps, and other "rift" features.

Additional mapping of the San Andreas fault in the study area since the 1974 SSZ maps were issued includes Buchanan-Banks, et al. (1978) and Dibblee (1979b, c). Buchanan-Banks, et al. compiled faults (based on the work of others) in the south-central Coast Ranges at a scale of 1:250,000 and classified faults based on their recency of activity (figiure 1). They classified the San Andreas fault as historically active in the study area. Dibblee (1979b, c) mapped traces of the San Andreas fault in the study area that generally correspond with faults mapped by Brown (1970) (figures 2c, 2d). Dibblee mapped Holocene deposits as offset along the San Andreas fault (figures 2c, 2d).

Short, northwest-trending faults located east of the San Andreas fault offset late Pleistocene and possibly Holocene alluvium and terrace deposits (localities 13, 14, figure 2d) (Dibblee, 1979c). These faults were not zoned in 1974.

Abundant evidence of fault creep has been observed along the San Andreas fault (Nason, 1971; Schultz and Burford, 1979; Burford and Harsh, 1980) (figures 2c, 2d). Creep rates along the San Andreas fault range from 13mm/yr at the northern end of the study area to 16mm/yr at the southern end of the study area (Schultz and Burford, 1979; Burford and Harsh, 1980). Creep rates at the Cienaga Winery, located 3 km northwest of the study area, are 12mm/yr and are 21 to 23mm/yr at Melendy Ranch, located 5 km southeast of the study area (Schultz and Burford, 1979).

CALAVERAS FAULT

The Calaveras fault is a major right-lateral strike-slip fault characterized by as much as 24 km of cumulative late Cenozoic strike-slip displacement (Page, 1982). Quaternary-active traces of the Calaveras fault zoned for special studies in 1974 were based on Kilburn (1972) in the Tres Pinos quadrangle, Dibblee (p.c. 1973) in the Paicines quadrangle, and Wilson (1943) in the Cherry Peak quadrangle (figures 2b-2d). In addition, air photo lineaments based on mapping by CDMG staff were zoned in 1974 (figures 2b-2d). The Calveras fault depicted on the 1974 SSZ maps forms an extremely complex zone of distributive faults.

Mapping of the Calaveras fault since the 1974 SSZ maps were issued includes Dibblee and Rogers (1975), Buchanan-Banks, et al. (1978), and Dibblee (1979a, b, c) (figures 2b-2d). Dibblee and Rogers (1975) mapped the Calaveras fault as concealed by late Pleistocene and Holocene alluvium in the Tres Pinos quadrangle. Dibblee (1979 a, b, c) mapped much of the Calaveras fault as concealed by late Pleistocene and Holocene terrace deposits and alluvium along the San Benito River (figures 2b-2d). Late Pleistocene and possible Holocene offset along the Calaveras fault mapped by Dibblee (p.c., 1973; 1979a, b, c) occurs at localities 2, 3, and 4 (figures 2b-2d).

Buchanan-Banks, et al. (1978) classified traces of the Calaveras fault as Holocene active only in the Tres Pinos and northern Paicines quadrangles (figure 1). These faults generally do not correspond with the faults mapped by Dibblee and Rogers (1975) or Dibblee (1979a, b), although there is some agreement between the Holocene faults of Buchanan-Banks et al. (figure 1), and some photo lineaments mapped by CDMG (figures 2b, 2c).

A late Quaternary slip-rate of 11mm/yr was calculated along the Calaveras fault, based on a right-laterally offset terrace deposit (locality 5, figures 2c, 3c) (J. Perkins, U.S.G.S., p.c., October 1984). The offset terrace deposits at this location were radiocarbon-dated at about 13,000ybp (Perkins, p.c., 1984). Mapping by Perkins along the Calaveras fault is not yet complete, and copies of the maps were not available to this writer at this time. Air photo lineaments previously mapped by CDMG (1974b) only locally correspond with the faulting at locality 5 (refer to Calaveras fault air photo interpretation section of this report and figure 3c for a re-interpretation of faults at locality 5). Dibblee (1979b) did not map a fault at this location (figure 2c).

PAICINES FAULT

The Paicines fault, a branch of the Calaveras fault, is a northwest-trending, right-lateral strike-slip fault (Wilson, 1943, Dibblee, 1981). Quaternary-active traces of the Paicines fault zoned for special studies in 1974 were based on mapping by Dibblee (p.c., 1973) in the Paicines quadrangle and Wilson (1943) in the Cherry Peak quadrangle (figures 2c, 2d). Air photo lineaments mapped by CDMG (1974a) were the basis for zoning in the Tres Pinos quadrangle because no faults previously had been mapped along this trend (figure 2b).

Mapping available after the 1974 SSZ maps were issued includes Dibblee and Rogers (1975) in the Tres Pinos quadrangle and Dibblee (1979a, b, c) (figures 2b-2d). Dibblee (1979a, b, c) mapped offset late Pleistocene terrace deposits and alluvium along the Paicines fault and, locally, offset Holocene alluvium in the Cherry Peak quadrangle (figures 2b-2d). Mapping by Dibblee (1979a, b, c) generally corresponds with the mapping of Wilson (1943) in the Cherry Peak quadrangle and with CDMG air photo lineaments in the Tres Pinos quadrangle, although differences in detail exist (figures 2b, 2d).

Wilson (1943) stated that the Paicines fault was similar in character to the San Andreas fault and that it was delineated by geomorphic evidence of Recent (Holocene) strike-slip faulting. The fault was exposed in a stream canyon at locality 6 (figure 2d) (Wilson, 1943). Wilson indicated that the fault plane was vertical and that San Benito Gravels were offset. He did not mention whether soil horizons were offset, although it is unlikely that datable soils would develop on the relatively unstable surfaces at locality 6.

Buchanan-Banks, et al. (1978) classified the Paicines fault as Holocene active, based on youthful geomorphic features and evidence of fault creep. An alinement array was placed across the Paicines fault at locality 7 (figures 2b, 3b) (Harsh and Pavoni, 1978). An average right-lateral fault creep rate of 6mm/yr was observed for the period between 1973 and 1977.

Harms, et al. (1984) have established approximate ages for a series of nested terraces along Tres Pinos Creek that have been offset by the Paicines fault (figure 3b). The ages of the terraces were determined by degree of soil development and should be considered preliminary at this time (Hardin, p.c., October 1984). The "C" terrace, which is mapped as offset by the Paicines fault by Dibblee (1979a), has been dated at about 40,000ybp, with an uncertainty ranging to 140,000ybp.

TRES PINOS FAULT

The Tres Pinos fault zoned for special studies in 1974 is assumed to be a right-lateral strike-slip fault, but direct evidence of the style of displacement is not well documented (figures 2b, 2c). Traces of the Tres Pinos fault zoned for special studies in 1974 were based on mapping by Kilburn (1972) and air photo lineaments mapped by CDMG (1974a, 1974b) (figures 2b, 2c). Mapping in this area since 1974 includes Dibblee and Rogers (1975) and Dibblee (1979a, b) (figures 2b, 2c). Dibblee (1981) indicated that the Tres Pinos fault is a northeast-dipping reverse fault.

The Tres Pinos fault was called the Bolado Park fault by both Taliaferro (1945) and Kilburn (1972). Taliaferro mapped an approximately located fault that offsets recent alluvium and as a well-located fault in older bedrock. However, it is questionable whether Taliaferro intended to identify recently active faults in the area because he does not map the Calaveras fault in the Hollister 15-minute quadrangle and all of the faults mapped in young alluvium are shown as approximate (he did not use a concealed symbol). Therefore, Taliaferro's fault trace is not shown on figure 2b.. Kilburn (1972) mapped the Tres Pinos (Bolado Park) fault as a near-vertical fault with down-to-the-west displacement. Kilburn mapped the fault as concealed by recent alluvium and Plio-Pleistocene San Benito Gravels. However, he shows the fault as offsetting San Benito Gravels as much as 240m in cross-section C-C' (figure 4 from Kilburn, 1972). The inferred segment of the Tres Pinos fault at locality 8 offsets Cretaceous sedimentary rocks (figure 2b).

Kilburn (1972) contoured groundwater levels in the Hollister Valley for 1968. The Calaveras fault is shown to significantly offset the water-table contours, as does the Quien Sabe fault zone. Groundwater contours are not offset along the Tres Pinos fault north of Highway 25 (Sec. 7, T135, R6E). To the south, the water table is apparently truncated against the inferred fault.

Several site-specific fault investigations have been performed along the northern half of the Tres Pinos fault (figure 2b). Leighton and Associates (1974a) found equivocal evidence for recent faulting. One trench was excavated, based on "contact relationships" observed in a northwest-trending streambed. Deformed sediments identified as Plio-Pleistocene San Benito Gravels were observed in the trench and "distortion of the sediments was evident throughout the vertical section of the trench." However, no fault plane was depicted in the trench log and no mention of discrete shears or orientation of shears was made. The trench log is highly diagrammatic and is very difficult to interpret. The inferred fault was projected to the northwest along a N45°W trend, based on sulphur springs located just north of Highway 25.

Johnson and Associates (1980) trenched a "linear swale" north of Highway 25 and exposed evidence of late Quaternary offset (locality 25, figure 2b). Several near-vertical shears in trench ET-1 truncate near-horizontal beds identified as older alluvium and terrace deposits (probably late Pleistocene). The trend of the shears ranges from N12°E to N17°W and horizontal striations were observed on one fault plane (figure 4). The shears are associated with an approximately 10-foot-wide shear zone described as gray-green clay gouge. The easternmost shear (N12°W 72°E) apparently offsets the "topsoil"-older alluvium contact and is inferred to continue up into the topsoil, which is probably Holocene colluvium. Two additional trenches were excavated, although neither trench was placed along the trend of faults exposed in ET-1. No evidence of strike-slip faulting was reported, although minor normal and reverse faulting was reported. These minor shears may be related to landsliding rather than faulting.

Terratech (1977) excavated two trenches along a northern projection of the Tres Pinos fault (figure 2b). Horizontally bedded older alluvium was observed in the exposures; no evidence of faulting was observed.

O'Rourke and Associates (1983) conducted a site investigation just west of the zoned Tres Pinos fault (figure 2b). They concluded that a linear depression used to infer the location of the segment of the Tres Pinos fault zoned in 1974 is more consistent with erosion or a shallow landslide rather than active faulting. A weak tonal lineament was trenched and evidence of faulting was not observed.

QUIEN SABE FAULT ZONE

The Quien Sabe fault zone is a complex zone of essentially right-lateral strike-slip faults with a generally down-to-the-west component of vertical displacement (Dibblee, 1979a; Dibblee, 1981; Dibblee and Rogers, 1975; Kilburn, 1972) (figures 2a, 2b). Cumulative vertical displacement may total as much as 760 meters along segments of the eastern Quien Sabe fault zone (Ausaymas fault of Kilburn, 1972). The amount of right-lateral strike-slip displacement across the fault is not known. Traces of the Quien Sabe fault zoned for special studies in 1974 were based on mapping by Taliaferro (1945) and Kilburn (1972) (figure 2b). Additional faults were zoned, based on air photo interpretation by CDMG (figure 2b). Taliaferro mapped an approximately located, northwest-trending fault in the Tres Pinos quadrangle that is shown to offset recent alluvium. Kilburn mapped an approximately located fault he termed the Santa Ana fault that offsets recent alluvium (figures 2a, 2b). Elsewhere the fault is overlain by younger and older alluvium (figure 2a).

Mapping since the 1974 SSZ map of the Tres Pinos quadrangle was issued includes Dibblee and Rogers (1975) and Dibblee (1979a) (figure 2a, 2b). Both Dibblee and Rogers (1975) and Dibblee (1979a) mapped late Pleistocene and Holocene alluvium as offset locally along the Quien Sabe fault, both in the Tres Pinos and Three Sisters quadrangles (figures 2a, 2b). Elsewhere, both Holocene and Pleistocene alluvium are shown as not offset. Kilburn (1972) and Dibblee and Rogers (1975) mapped a fault concealed by Holocene alluvium, named the Santa Ana fault by Kilburn, that branches west of the Quien Sabe fault (figure 2a). Kilburn indicates that segments of the Quien Sabe fault in the Three Sisters quadrangle truncate groundwater level contours forming prominent groundwater subbasins.

BRADLEY FAULT

The Bradley fault of Dibblee (1979a) is a northwest-trending fault that locally offsets Holocene alluvium, down to the west (figure 2b). Most of the Bradley fault was not zoned for special studies in 1974, although an air photo lineament mapped by CDMG (1974a) generally corresponds with the northern segment of the Bradley fault (locality 10, figure 2b). The Bradley fault is concealed by Holocene and late Pleistocene alluvium south of locality 11 (figure 2b).

Dibblee (1979a) mapped an inferred fault that offsets Pleistocene alluvium at locality 12 (figure 2b). Holocene alluvium is not offset north and south of this fault.

PINE ROCK FAULT

The Pine Rock fault, a northwest-trending strike-slip fault zoned for special studies in 1974, was based on mapping by Wilson (1943), Dibblee (p.c., 1973), and locally air photo lineaments mapped by CDMG (figures 2c, 2d). Wilson mapped Plio-Pleistocene San Benito Gravels offset along the fault, but late Pleistocene terrace deposits and Holocene alluvium are not offset. The approximately located fault mapped by Dibblee (p.c., 1973) is inferred to offset Holocene terrace deposits. However, subsequent mapping by Dibblee (1979b, c) depicts the Pine Rock fault as concealed by Pleistocene and Holocene alluvium (figures 2c, 2d).

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the south Hollister study area was accomplished using U.S. Geological survey air photos (WRD, 1966, scale 1:12,000; SFB, 1974, scale 1:20,000).

Approximately four days were spent in the study area in late October and late November 1984 by this writer in order to verify selected fault segments interpreted from air photos. In addition, subtle features not observable on the air photos were mapped in the field. Results of air photo interpretation and field observations by this writer are summarized on figures 3a-3d.

SAN ANDREAS FAULT

The San Andreas fault in the study area is generally very well-defined and is characterized by abundant geomorphic evidence of Holocene faulting, including closed depressions, right-laterally offset and beheaded drainages, sidehill benches and troughs, and scarps (figures 3c, 3d). Minor drainages are systematically offset right-laterally up to 30 meters at locality 15 (figure 3c). The principal active trace of the San Andreas fault locally is concealed by very young (late Holocene?) terrace and floodplain deposits along the San Benito River. However, subtle geomorphic features and linear tonal features can be identified in a number of places in these young deposits. In addition, evidence of right-lateral fault creep was noted (figures 3c, 3d).

Generally, there is good agreement in the location of the principal active traces of the San Andreas fault mapped by Dibblee, Brown, and this writer, although differences in detail exist (figures 2c, 2d, 3c, 3d). The air photo lineaments at locality 1, originally zoned in 1974, are not well defined and could not be verified as Holocene-active by this writer (figure 2c).

The short, northwest-trending faults east of the San Andreas fault mapped by Dibblee (1979c) at localities 13 and 14 (figures 2d, 3d) generally are well-defined and are characterized by geomorphic evidence of Holocene normal faulting (figure 3d).

CALAVERAS FAULT

The Calaveras fault in the study area locally is well-defined, but significant segments of the fault are obscured by landslides or concealed by late(?) Holocene alluvium and terrace deposits (figures 3b, 3c). The active trace of the Calaveras fault complexly joins the Paicines fault in the Tres Pinos and Paicines quadrangles and the names assigned by various authors seem somewhat arbitrary. Faults mapped by this writer only locally agree with mapping by Dibblee and Rogers (1975) and Dibblee (1979a, b, c) (figures 2b-d, 3b-d). General agreement with faults mapped by this writer and air photo lineaments zoned in 1974 is apparent in parts of the Tres Pinos and Paicines quadrangles, but differences in detail exist (figures 2b-d, 3b-d).

Segments of the Calaveras fault in the Tres Pinos and Paicines quadrangles are well-defined and are characterized by geomorphic evidence of Holocene faulting, such as closed depressions, right-laterally deflected drainages, scarps and troughs in Holocene terrace deposits and alluvium, right-laterally offset ridges and terrace risers, and tonal lineaments in latest Pleistocene to Holocene alluvium (localities 5, 16-19, figures 3b, 3c).

The Calaveras fault is significantly less well-defined southeast of Highway 25 (figures 3c, 3d). Faults mapped by Dibblee (1979c) locally were verified by this writer and are characterized by broad linear troughs and linear ridges in Plio-Pleistocene San Benito gravels, right-laterally deflected drainages (non-systematic), saddles, and benches (figure 2d). Geomorphic evidence of Holocene faulting, such as well-defined sidehill troughs, sidehill benches, linear scarps, and closed depressions was not observed. However, broadly warped surfaces and scattered depressions suggest that distributive tectonic deformation has occurred in late Quaternary time.

PAICINES FAULT

The Paicines fault generally is well-defined throughout most of the study area (figures 3b-3d). Faults mapped by Dibblee (1979a, b, c) generally were verified by this writer, although differences in detail exist (e.g. localities 20-23, figure 3b, locality 24, figure 3c). Geomorphic evidence of Holocene strike-slip faulting, such as closed depressions, sidehill benches and troughs, systematically right-laterally deflected drainages, beheaded drainages, and tonal lineaments in Holocene alluvium characterizes much of the Paicines fault (figures 3b-3d). The fault generally is not well-defined in the Swanson Bluff area (locality 24, figure 3c). This is partly due to massive landsliding just northwest of Paicines and, probably, because of the complex nature of faulting at this location. Segments of the active Calaveras and Paicines faults seem to converge near Paicines, possibly forming an overlapping, right-stepping pattern (Aydin and Page, 1984). The large reservoir just west of Highway 25 is probably a man-modified closed depression, based on a description by Wilson (p. 255, 1943), and indicates a component of extensional deformation in this area (figure 3c).

Fault creep along the Paicines fault has been documented in the Tres Pinos quadrangle by Harsh and Pavoni (locality 7, figure 3b). Additional evidence of fault creep along the Paicines fault was observed by this writer. Two localities along Southside Road display left-stepping en echelon cracks (localities 21 and 22, figure 3b). The deformation in Southside Road at locality 22 is associated with a subtle, east-facing scarp. The road has been patched in an attempt to level out the scarp. A few meters south of the road, the fault is delineated by a modified east-facing scarp in Holocene terrace deposits and by an apparent right-lateral offset of rows of walnut trees (figure 3b). To the northwest at locality 21, well-defined, left-stepping en echelon cracks across Southside Road align with a subtle, east-facing scarp in a young terrace. The age of this terrace, known as the "Schoolhouse Terrace," has been determined to be between 1,000 and 12,000ybp, based on soil profile development (Hardin, p.c., October 1984).

TRES PINOS FAULT

Air photo interpretation by this writer was done primarily to verify the fault traces zoned for special studies in 1974 (figures 2b, 2c). Generally, the Tres Pinos fault is poorly defined and most traces zoned in 1974 could not be verified as indicative of recently active faulting. Most fault traces seem to be modified by erosion, and this writer was impressed with the general lack of geomorphic evidence of systematic right-lateral strike-slip faulting.

A short, northwest-trending fault just south of Tres Pinos mapped by Dibblee (1979a) and CDMG (1974a) was verified by this writer (locality 9, figure 2b). The fault is characterized by a broad linear trough, closed depressions, and two right-laterally deflected drainages. The fault could not be followed to the northwest or southeast (figure 2b).

Locally, geomorphic evidence of recent faulting at the Johnson and Associates (1980) site consists of a northwest-trending, southwest-facing scarp (locality 25, figure 2b). The scarp cannot be traced very far and associated geomorphic evidence of recent strike-slip faulting was not observed by this writer. A subtle, arcuate scarp suggests landsliding at the site, although the slope failure is probably very old. A landslide seems consistent with the minor shears exposed in trenches ET-2 and ET-3, but the wide gouge zone observed in ET-1 is not consistent with relatively minor shearing along the lateral margin of a landslide.

Geomorphic evidence of recent faulting was not observed by this writer at the Leighton and Associates (1974a) site (locality 26, figure 2b). The escarpment in Pleistocene alluvium was probably formed by lateral stream erosion as indicated by the broadly arcuate trend of the escarpment (figure 2b).

QUIEN SABE FAULT ZONE

The Quien Sabe fault zone is generally well-defined in the Three Sisters and Tres Pinos quadrangles (figures 3a, 3b). Faults mapped by Dibblee and Rogers (1975) and Dibblee (1979a) generally were verified by this writer, although differences in detail exist. Additional discontinuous faults with generally down-to-the-west vertical displacement were mapped by this writer in the Three Sisters quadrangle, based on air photo interpretation and limited field mapping (localities 27 and 28, figure 3a). These discontinuous, probably normal faults offset alluvium and alluvial fans of late Pleistocene and, possibly, Holocene age (figure 3a).

A significant component of right-lateral strike-slip displacement was observed along the Quien Sabe fault zone in Santa Ana Valley (figure 3b). Sidehill troughs, linear ridges, closed depressions, beheaded and right-laterally deflected drainages suggest Holocene strike-slip activity (figure 3b). South of locality 29, the Quien Sabe fault is delineated by a broad, alluvial-filled trough (figure 3b). Vague tonal lineaments in alluvium, linear and right-laterally deflected drainages suggest possible Holocene activity (figure 3b).

Scarp profiles were measured across along several segments of the Quien Sabe fault zone (figures 3a, 3b). Age assessments and comparisons cannot be made with fault scarp profile data developed by Wallace (1977) and Bucknam and Anderson (1979) along normal faults in Nevada and Utah. However, it is useful to know the scarp heights, and therefore estimate the magnitudes of late Pleistocene displacement along segments of the Quien Sabe fault zone. The maximum heights of west-facing scarps in alluvial fans along the Quien Sabe fault range from 4.6-6.7m (figures 3a, 3b).

Possible evidence of multiple offsets was observed at locality 30 where a west-facing scarp in late Pleistocene alluvium has at least two measurable scarp-slope angles (figure 3a). A distinct terrace in a small drainage incised in the scarp 10 to 15 meters north of locality 30 also suggests multiple traces events. It is unlikely that the composite scarp was formed by lateral stream erosion. ?

Soil developed on alluvium offset by the Quien Sabe fault generally is classified as the Rincon soil series by the U.S. Soil Conservation Service (SCS, 1969). The soil profile is characterized by a weakly to moderately developed B soil horizon with thin, patchy, clay films, 10-YR colors, and some carbonate in both the B horizon and the clay loam C horizon. The age of the soil is probably late Wisconsin (10,000-30,000ybp) rather than Holocene. Mapping by the SCS is somewhat generalized, as no distinction seems to have been made between soils developed on latest Pleistocene alluvial fans and alluvial fans that clearly seem to be Holocene, based on constructional morphology. Therefore, age-dating of surfaces offset by the Quien Sabe fault is only approximate until more detailed studies can be made.

Slip-rates have not been calculated for the Quien Sabe fault zone and considerable work remains to further constrain the ages of offset deposits and magnitudes of displacement along the fault. However, a very tentative slip-rate ranging from 0.22mm/yr (offset during last 30,000ybp) to 0.67mm/yr (offset during last 10,000ybp) is estimated, based on vertically offset alluvial fans. This slip-rate, which does not consider any component of right-lateral offset along the fault, should only be considered as a minimal approximation.

BRADLEY FAULT

Segments of the Bradley fault are locally well-defined and are characterized by geomorphic evidence suggesting Holocene right-lateral and minor vertical displacement (localities 31 and 32, figure 3b). However, the southern, concealed projection of the Bradley fault mapped by Dibblee (1979a) could not be verified by this writer. Two minor faults west of locality 31 have minor down-to-the-east displacements in older alluvium, but neither could be traced southward into Holocene alluvium. The western trace is delineated by a linear scarp and closed depression at locality 12 (figure 3b).

PINE ROCK FAULT

The Pine Rock fault locally is delineated by geomorphic evidence of late Quaternary right-lateral strike-slip faulting (broad linear trough, saddles, linear ridges and right-laterally deflected drainages) (figures 2d, 3d). However, geomorphic evidence of Holocene strike-slip faulting was not observed by this writer, and the faults zoned in 1974 are generally not well-defined and could not be verified by this writer (figures 2c, 2d).

SEISMICITY

Seismicity in the study area is depicted in figure 5. Much of the seismicity associated with the San Andreas fault zone has been excluded from this figure due to the extremely large number of M 1.0 earthquakes. The northwest-trending alignment of epicenters is located as much as 3-1/2 km west of the surface trace of the San Andreas fault, indicating that problems with epicenter locations exist, at least with velocity modeling across the San Andreas fault. The Quien Sabe, Calaveras, and Paicines fault zones are all seismically active at depth, as is the Tres Pinos fault. A northwest-trending alignment of epicenters is located about 2 km east of the previously zoned Tres Pinos fault. The east-dipping fault in bedrock mapped by Dibblee (1979a) may be associated with these epicenters, but geomorphic evidence of surface faulting is lacking. It is apparent that most of the area between the San Andreas and Quien Sabe faults is seismically active. Broadly warped surfaces and scattered closed depressions observed in many parts of the study area also suggest that distributive tectonic deformation has occurred in late Quaternary time.

CONCLUSIONS

SAN ANDREAS FAULT

The San Andreas fault, a major right-lateral strike-slip fault, is well-defined in the study area and is delineated by geomorphic evidence characteristic of Holocene strike-slip faulting (e.g. locality 15, figures 3c, 3d). Generally, faults mapped by Brown (1970) and Dibblee (1979b, 1979c) were verified by this writer, although differences in detail exist, such as northwest of Sec. 7, T14S, R6E and in Sec. 21 and 27, T14S, R6E (figures 2c, 3c).

The San Andreas fault is characterized by fault creep in the study area (figures 2c-2d, 3c-3d). Fault-creep rates along the fault range from 13mm/yr at the northern end of the study area to 16mm/yr at the southern end of the study area (Schultz and Burford, 1979; Burford and Harsh, 1980).

CALAVERAS FAULT

The Calaveras fault is a major right-lateral strike-slip fault. However, traces of the Calaveras fault zoned for special studies in 1974 in this study area form a wide and complex zone of distributive faulting. The Calaveras fault locally is well-defined and is delineated by geomorphic evidence of Holocene strike-slip faulting (localities 5, 16-19, figures 3b, 3c). However, significant areas along the Calaveras fault are obscured or concealed by landslides and Holocene terrace and fluvial deposits (figures 3b, 3c). Perkins (U.S.G.S., p.c., 10-84) calculated a late Quaternary slip-rate of 11mm/yr along the southern Calaveras fault, based on offset latest Pleistocene terrace deposits (13,000ybp) (locality 5, figure 3c).

Generally, faults mapped by Dibblee (1979b, c, d), Wilson (1943), Kilburn (1972), and Dibblee and Rogers were only locally verified by this writer (figures 2b-d, 3b-d). Buchanan-Banks, et al. (1978) did not classify the Calaveras fault as Holocene active southeast of Highway 25. Although the Calaveras fault is characterized by fault creep north of the study area, no evidence of creep was observed along the fault in the study area.

PAICINES FAULT

The Paicines fault is a right-lateral strike-slip fault that is considered to be a branch of the Calaveras fault in this report. Both the Calaveras and Paicines faults are delineated by geomorphic evidence characteristic of Holocene strike-slip faulting northwest of Highway 25, but to the southeast, recent faulting seems to occur only along the Paicines fault (figures 3c, 3d).

The Paicines fault in the study area generally is well-defined and is characterized by geomorphic evidence of Holocene strike-slip faulting (localities 6, 21, 22, figures 3b, 3d). Faults mapped by Dibblee (1979a, b, c) and Wilson (1943) generally were verified by this writer, although differences in detail exist. The Paicines fault is obscured by massive landslides southeast of Sec. 10, T15S, R7E (figure 3d).

Fault-creep along the Paicines fault was observed at localities 21 and 22 by this writer (figure 3b). Harsh and Pavoni (1978) calculated an average creep-rate of 6mm/yr along the Paicines fault (locality 7, figure 3b). Buchanan-Banks, et al. (1978) classified the Paicines fault as Holocene-active, based on youthful geomorphic features and evidence of fault creep.

TRES PINOS FAULT

The Tres Pinos fault is assumed to be a right-lateral strike-slip fault, but the style of displacement is not well-documented. Kilburn (1972) mapped the Tres Pinos fault (which he termed the Bolado Park fault) as a near-vertical fault with down-to-the-west displacement. Subsequent mapping by Dibblee and Rogers (1975) and Dibblee (1979a, b) do not depict those traces of the Tres Pinos fault as zoned for special studies in 1974, except for a short, northwest-trending fault segment at locality 9 (figures 2b, 3b). The Tres Pinos fault generally is poorly defined and geomorphic evidence of Holocene faulting was not observed by this writer. Most fault traces seem to be modified by erosion, and this writer was impressed with the general lack of geomorphic evidence of systematic, right-lateral strike-slip faulting. Faults zoned for special studies in 1974 generally were not verified by this writer (figures 2b, c).

Several site-specific fault investigations have been conducted along the northern Tres Pinos fault (figure 2b). Evidence of recent faulting exposed by Leighton and Associates (1974a) is equivocal. The trench log is diagrammatic and difficult to interpret. Geomorphic evidence of recent faulting at the site, a southeast-facing escarpment, is broadly arcuate and was probably formed by lateral stream erosion.

A trench excavated by Johnson and Associates (1980) exposed evidence of late Quaternary and possibly Holocene strike-slip displacement (figures 2b, 4). A subtle southwest-facing scarp coincided with the fault exposed in the trench, but additional geomorphic evidence of faulting was not observed northwest and southeast of the site. Subtle geomorphic evidence at this site suggests landsliding, and it is possible that the near-vertical shears exposed in ET-1 represent the lateral margin of a landslide. However, the broad gouge zone exposed in ET-1 seems to argue against landsliding.

Additional fault investigations along the Tres Pinos fault did not expose evidence of faulting (Terratech, 1977; O'Rourke and Associates, 1983). Generally, continuous near-horizontal beds of Pleistocene alluvium were observed.

Significant deformation in late Pleistocene alluvium is not apparent along traces of the Tres Pinos fault north of Highway 25. Bedding planes in late Pleistocene alluvium are near-horizontal in trenches excavated by Johnson and Associates (1980), Terratech (1977), and O'Rourke and Associates (1983). Assuming that the alluvium north of Highway 25 correlates with the "A" terrace of Hardin (p.c., 1984), the age of the alluvium is at least 150,000ybp. If the Tres Pinos fault is characterized by a slip-rate of about 1mm/yr, the alluvium should be laterally offset at least 150 meters. It is possible, though perhaps not probable, that this magnitude of offset would cause bedding planes to strike subparallel to the trend of the Tres Pinos fault. Sparse observation of data tends to neither support nor refute this assumption, but the apparent lack of structural deformation seems consistent with the lack of geomorphic evidence characteristic of Holocene faulting. However, minor, discontinuous faulting cannot be ruled out, based on the deformation observed by Johnson and Associates (1980). In addition, the Tres Pinos fault appears to be seismically active at depth (figure 5).

QUIEN SABE FAULT ZONE

The Quien Sabe fault zone is characterized by right-lateral strike-slip displacement with a component of generally down-to-the-west vertical offset (figures 3a, 3b). The Quien Sabe fault zone generally is well-defined and is characterized by late Pleistocene and possible Holocene offset. Alluvial fans of probable late Wisconsin age, based on U.S.S.C.S. data, are offset up to 6m along the Quien Sabe fault zone (figures 3a, 3b). Fault scarps in alluvium are associated with closed depressions and, locally, evidence of multiple offsets, based on scarp profiles and terraces in minor Holocene drainages incised across the fault scarps (figures 3a, 3b). A late Quaternary slip-rate from 0.22mm/yr to 0.67mm/yr is estimated for the Quien Sabe fault zone, based on vertical offsets of alluvial fans. The magnitude and rate of strike-slip displacement is not known.

Faults mapped by Dibblee and Rogers (1975) and Dibblee (1979a) generally were verified by this writer, although differences in detail exist (figures 2a, 2b, 3b). Geomorphic evidence of Holocene faulting is less well-defined southeast of locality 29, although geomorphic features are permissive of Holocene offset (figure 3b).

BRADLEY FAULT

The Bradley fault is a northwest-trending, right-lateral strike-slip fault with a minor component of down-to-the-west vertical displacement. The fault is locally well-defined and offsets latest Pleistocene and Holocene alluvium (Dibblee, 1979a) (localities 31, 32, figures 2b, 3b). The northern extent of the Bradley fault, zoned for special studies in 1974 based on air photo lineaments mapped by CDMG staff, generally corresponds with mapping by Dibblee (1979a) and was verified by this writer (figures 2b, 3b). However, most of the Bradley fault mapped by Dibblee (1979a) is concealed by Holocene alluvium and could not be verified by this writer. Minor faults west of the Bradley fault are characterized by down-to-the-east vertical offset and have geomorphic features suggestive of Holocene displacement (locality 12, figure 3b).

PINE ROCK FAULT

The Pine Rock fault, a right-lateral strike-slip fault zoned for special studies in 1974, is generally not well-defined and is not delineated by geomorphic evidence of Holocene faulting (figures 2c, 2d, 3c, 3d). Late Pleistocene and Holocene alluvium is not offset along the fault (Wilson, 1943; Dibblee, 1979b, c), although short, discontinuous segments do offset late Pleistocene alluvium (figure 3d).

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1980).

SAN ANDREAS FAULT

Zone for special studies well-defined faults shown on figures 6c and 6d. Principal references cited should be Brown (1970), Dibblee (1979b), and this FER.

CALAVERAS FAULT

Zone for special studies well-defined faults shown on figures 6b and 6c. Principal reference cited should be this FER. Delete traces of the Calaveras fault southeast of Highway 25 zoned for special studies in 1974. These faults are not sufficiently active and well-defined.

PAICINES FAULT

Zone for special studies well-defined faults shown on figures 6b, 6c, and 6d. Principal references cited should be Dibblee (1979a, 1979b, 1979c), and this FER.

TRES PINOS FAULT

Zone for special studies well-defined segments of the Tres Pinos fault as shown on figure 6b. Delete traces of the Tres Pinos fault zoned for special studies in 1974 that are not sufficiently active and well-defined.

QUIEN SABE FAULT ZONE

Zone for special studies well-defined faults shown on figures 6a and 6b. Principal references cited should be Dibblee and Rogers (1975), Dibblee (1979a), and this FER.

BRADLEY FAULT

Zone for special studies well-defined segments of the Bradley fault and unnamed minor faults to the west as shown on figure 6b. Principal references cited should be Dibblee (1979a) and this FER.

PINE ROCK FAULT

Delete traces of the Pine Rock fault zoned for special studies in 1974. These faults are not sufficiently active or well-defined.

Report and aerial photos reviewed. I concur with these recommendations. Earl W. Hart 5/17/85

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Figure 4 (to FER-164). Log of trench ET-1 excavated by Johnson and Associates (1980); horizontal and vertical scales are equal. Refer to figure 2b for location of ET-1.